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FLIGHT OPERATIONS AND GUIDE BEAM SYSTEMS

T. Bohr

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16. Abstract

The history and perspectives of the instrument landing system are presented. The present operational requirements for these systems, as endorsed by the ICAO, are formulated and discussed.

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FLIGHT OPERATIONS AND GUIDE BEAM SYSTEMS

T. Bohr*

1. Introduction /2**

Requirements of pilots for safe landings after carrying out a flight are as old as aviation science itself. This landing maneuver is relatively simple if done according to vision, but there are certain limitations. When the vision is impaired, considerable difficulties occur. Therefore, attempts were already made relatively early to find additional aids for the pilot which would make safe landing possible under poor visibility conditions with a high degree of probability. Landing methods were developed which might appear quite bold from the present-day point of view. However, considering the aircraft and conditions of former times, the methods were relatively successful. Because new aircraft types were introduced which required rigid landing fields because of their size, the requirements for guide beam systems increased. Especially the accuracy requirements increased. The most important problem was still to provide a safe approach to a runway. The landing aids primarily were concentrated during the final approach phase. Safety improvements were introduced with which it was possible to reduce the time duration of the visible phase required for checking the successful approach and required for the landing itself. This technique is relatively well controlled by the present-day system. The problem of the

*Federal Agency for Flight Safety, Frankfort/Main, Germany.
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capacity of airports under very poor visibility conditions has become acute. This problem, as well as the problem of establishing guide beam systems and the fact that new aircraft types are being continuously introduced as well as new in-flight profiles, have made it necessary to introduce an extended system.

The development of the guide beam systems (here we are referring to those for approach and landing) can be classified into three phases according to my opinion (Figure 1):

1. Introduction of the guide beam systems beginning with the first experiments up to the conception of mature systems. This phase starts about 1920 and extends up to 1945.

2. Improvement of the available systems or of the introduced, standardized systems. Safety was especially stressed, as well as accuracy and integrity. This development extends up to the introduction of automatic landings. This phase starts in 1949 with the standardization of the ILS and concludes about 1966 with the establishment of a standard agreed to at the COM-CPS-Conference of the ICAO, which is still in effect today. The introduction of the corresponding systems is still in progress, and a preliminary final point has been established at 1985. /3

3. Extension of the guide beam systems because of the operational requirements which had increased in the meantime. These are primarily directed at the increase of the capacity of the system while maintaining its integrity, the extension of the system to the approach phase and the application to new flight profiles. This phase starts as a conception phase in 1966 (1967 RTCA SC-117, 1968 AWOP) and will probably be completed in 1977. The introduction of a corresponding new system will be carried out in steps starting in 1980.

DEVELOPMENT OF THE GUIDE BEAM SYSTEMS

Introduction	1936 - 1945
Improvements (ILS)	1949 - 1966 1949 Appendix 10 1966 COM OPS Distribution and Operation up to 1985
Extension	1966 - 1977 1972 Seventh Aerodynamics Conference of ICAO 1977 Decision 1980 Introduction

Figure 1.

2. Where Are We Today?

The so-called instrument landing systems (ILS) has been introduced on a world-wide scale and has been standardized since 1949 on the international level. The operational requirements for this system (operational objectives) contemplate a transition to reduced visibility conditions during landings in steps. In general, they are known as so-called operational steps and include operations up to absolute zero visibility conditions (Figure 2). The resulting requirements for the ILS are, therefore, intentionally directed towards increased accuracy, safety, and integrity. The guidance essentially is concerned with the final approach phase. The requirements in the transition range with exploitable information are, therefore, small, and no requirements for guidance under erroneous approach conditions have been established. The system offers control in two planes and, in addition, furnishes some distance data. The ILS can be looked upon as a typical system at the end of the improvement phase.

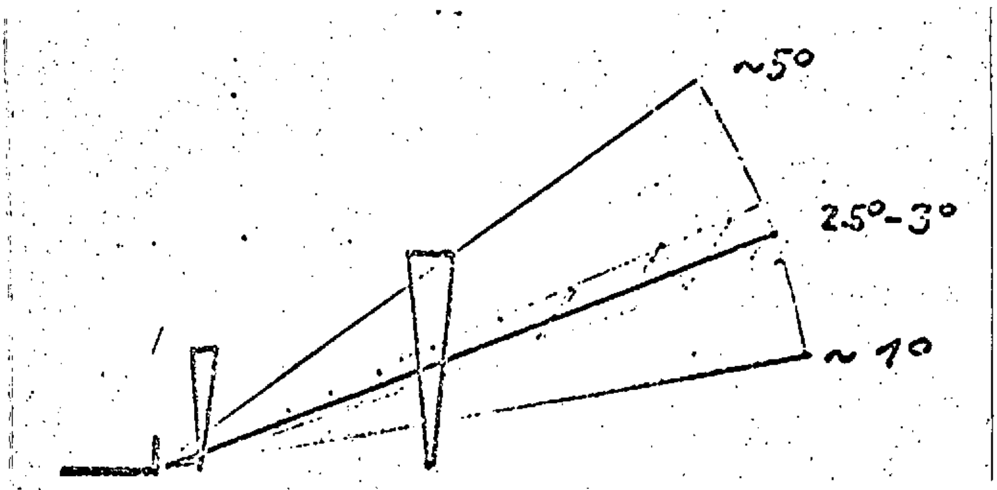
The configuration of the ILS can be assumed to be generally known (Figure 3). The components of the system, the landing path, glide path, and entry signal are related to installation points with relatively small tolerances. The ILS only provides a fixed approach path and a fixed glide path angle. The range within which linear information is available is very narrow.

The guide beam system corresponds to the state of the art of the onboard units: except for purely manual flying, the available flight controllers only allow a very limited motion during the approach, which is limited along two fixed axes. The possibility of flying arbitrary trajectory curves is not available. By the separation along two axes, the final state

ILS: OPERATIONAL OBJECTIVES

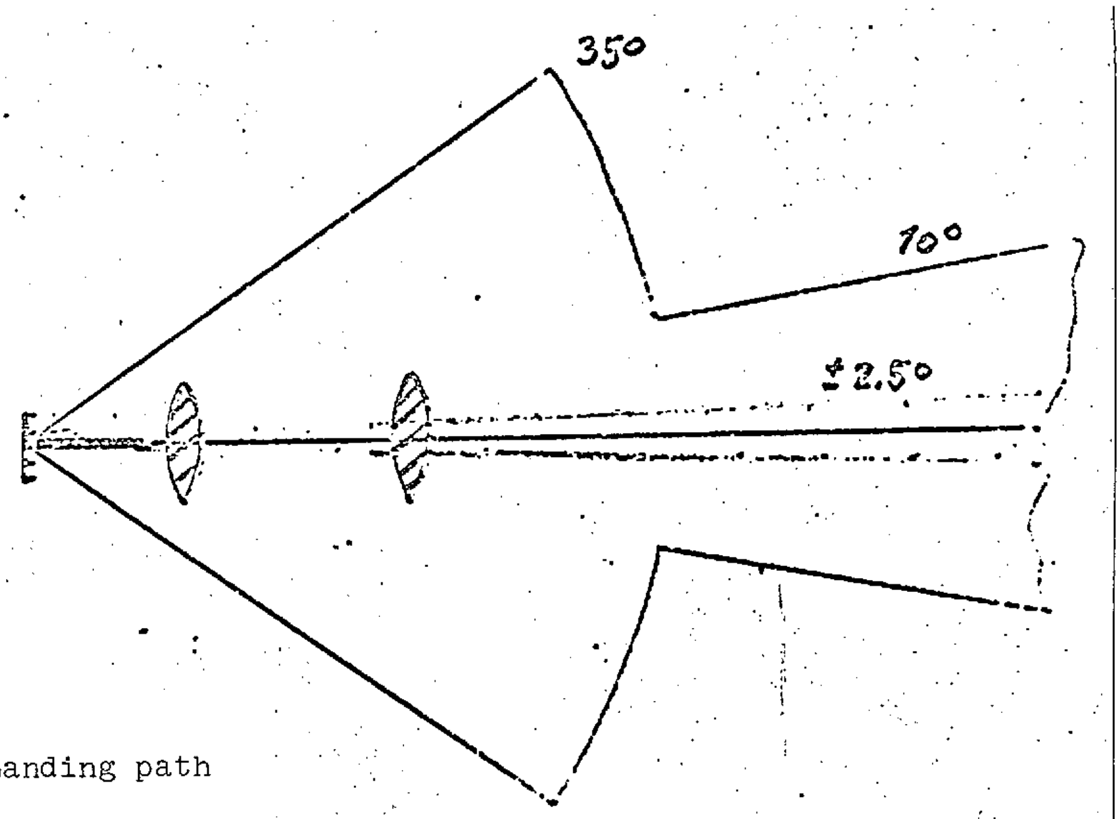
Operational State	Decision Altitude	Landing Runway Visibility
I	$\geq$ 50 m	$\geq$ 800 m
II	$\geq$ 30 m	$\geq$ 400 m
III A	0 m	$\geq$ 200 m
III B	0 m	$\geq$ 50 m
III C	0 m	0 m

Figure 2.



Approach signal

Glide path



Landing path

Region of linear information

Figure 3.

must have been reached along one of them. This results in the requirement for relatively long straight-line final approach paths. The leveling off process is done using additional sensors. Therefore, we have a relatively cumbersome and rigid system which has limited flexibility as far as operations are concerned. In addition, we have restrictions caused by the guide beam system itself, which are essentially caused by the technical concept.

Therefore, the question arises of what can be done with the system. Overall, this is quite a bit. The ILS makes it possible to introduce instrument landings at almost all important airports and runways. The development up to automatic landings could be carried out in a rational way. However, a corresponding effort will have to be made on the ground and on board, and the guide beam system, because of its nature as an air-derived system, will always represent the critical point as far as a fail-operational system is concerned. In spite of this, automatic landings can today be carried out with a very high certainty (10^{-7}) and the operational state III A has already been introduced for many runways. If we consider the remaining fraction of poor weather conditions, we may look upon it as the final state for all practical purposes. This system can be looked upon as a proven system within its limitations. This is also expressed by the fact that it will be used up to 1985. Significant improvements or changes of the system are hardly possible today. /3

Now what are the limitations of the ILS system? The restrictions mentioned above are often mentioned by the critics. However, it must be stated that the ILS satisfies the existing operational requirements in a satisfactory way. It was only designed for these requirements and can only be compared to them. The additional requirement for continuous distance indications can be indicated in a relatively simple manner. One important drawback for the ILS system is the relatively large wavelength used, which leads to considerable antenna dimensions and, secondarily, to extensive regions not covered by the system. Therefore, there are installation problems associated with the installation of the guide beam system. The costs for preparation of the terrain is often considerably higher than the technical equipment itself. Other criticisms which have been raised for the ILS also apply for new systems. For example, the susceptibility to reflections and shading effects, the erection problems (which can never be completely avoided for air-derived systems), as well as the costs of the unit. Any new system must consider these problems in detail in the same way. The essential limitation for use of the ILS is brought about by new operational requirements, which go outside of the original concept and, therefore, the ILS can no longer satisfy the new requirements. In the following, we will discuss this topic.

In summarizing, we may state that as far as the previously existing operational requirements are concerned, and we can only measure the ILS against such requirements, we have before us a highly developed and mature system. Everyone agrees that no basic improvements can be made to it. It can still be installed at a number of landing runways. The installation difficulties for the system are generally caused by the frequency limitations and the considerable space requirements. Also, the associated costs have an indirect effect. If we consider the time period over which the ILS was developed, one can state that it is a remarkably simple concept. The most important reason for replacing it by a new system is the new changed operational requirements and not basic technical difficulties of the ILS.

3. New Operational Requirements

/4

Soon after the end of the concept phase of the present-day ILS in 1966, which was characterized by achieving the required high safety standards and accuracy standards, new requirements became apparent which required an extension of the guide beam system (extension phase). The most important reason for this was the desirability of increasing the capacity of the airports significantly while retaining the existing safety levels. Also, new aircraft types were planned or being introduced, having new flight profiles. In addition, the new advanced technology was required to bring about simpler installation conditions and a more economical flexibility (modular concept).

The impetus for developing new operational requirements came from many sides. In 1967, basic work was carried out in the RTCA-SC 117; and in 1968 work on the AWOP was started. The results differ only slightly. There was international agreement on the preliminary operational requirements at the Seventh Aviation Conference of the ICAO in 1972. In addition, industry in the NIAG of the NATO is concerned with establishing requirements and selecting a system.

What are these requirements? The summary of the basic requirements as established by the ICAO are the following (Figure 4):

> It consists of the requirement for an accurate flight guidance system which makes it possible to control approach, landing, and erroneous approaches with a very high degree of safety under the following conditions:

<u>OPERATIONAL REQUIREMENTS ISAO</u>

Approach, Landing, and Erroneous Approach Guidance with High Safety Level and Precision:

1. at all airports and landing runways

2. maximum approach rate

3. no restriction due to visibility conditions during landing

4. VMC flexibility under all weather conditions

5. without system limitations with sufficient accuracy, reliability, and coverage for all possible flight methods

6. modularity and more simple compatible versions

7. support of noise reduction methods

Figure 4.

1. At most airports and runways

2. At a maximum approach rate

3. Without restriction caused by lower cloud limit or visibility during landing

4. With a flexibility which corresponds to the flexibility during approaches with visibility, as well as under all other weather conditions

5. Without restrictions caused by the guide beam system (except where these limitations can be accepted for reasons for economy and simplicity) and with an accuracy, a coverage range, a reliability and integrity which will make it possible to carry out any desired approach and landing procedure for any conceivable type of aircraft

6. With simplified versions of onboard and ground units for restricted operational conditions, but there must be compatibility between these versions, and

7. They must support the noise reduction procedures.

Of all these requirements, the general requirements for integrity and the avoidance of any limitation caused by visibility conditions represent a continuation of the standards already achieved with the ILS. The requirement for the introduction at almost all airports and with simplified versions of hardware (1 and 6) have a considerable effect on the technology to be used, as well as the cost and efficiency ratios. The requirement 7 is quite unmotivated and can be derived from the preceding requirements. This requirement could already be satisfied by requirements 4 and 5. The important requirements for operation are requirements 2, 4, and 5. How must they be interpreted? /5

The operational requirements of the ICAO have been more clearly defined in 18 sub-definitions. We will not enumerate them here because of time limitations. The requirement for the maximum rate of motion at airports, which should not be limited by the system, can be understood considering the ILS. The ILS today is sometimes the restricting factor in capacity investigations, because it is influenced by overflight disturbances or by rolling processes, which encompass the so-called critical or sensitive ranges of the ILS. In the future, this is to be avoided in a new system.

The remaining requirements have the objective of increasing the capacity of airports as already mentioned. This will be done by new approach methods which are to be assured under all prevailing weather conditions. In addition, the introduction of new aircraft types is considered and the landing process has been enhanced by means of a leveling off procedure. In the requirements for flexibility during approaches corresponding to conditions with visibility, one realizes that the capacity of a trajectory system at the present time depends on the prevailing visibility conditions in a decisive way. This difference is considerably influenced by the fact that the pilot takes on some of the traffic control function when there is visual contact. He does this by manual flying corresponding to curved approach paths or by using velocity control to make time corrections. He also reduces the required separation during flight and on the ground. At the present time, it is not yet clear whether and how these conditions can be applied to a new flight control system with changed weather conditions. We only like to mention the fact that the related tolerance in the time prediction on the order of ± 10 seconds will be extremely difficult to realize for a five-minute range. The continuous adjustment of the approaches by surveillance of the ever-changing traffic picture, the shortening of the final approach (straight line) has limitations for automatic flying conditions. It is extremely difficult to calculate an optimum approach sequence by introducing various curved approach paths and to then transmit them to the aircraft. At the present time, it cannot be realized anyway because there are no suitable flight control systems. Velocity control in the restricted sense has at least the same effect as the influence of the different curved approach paths. At the present time, it is also not known how the traffic control on the ground can handle the increased approach capacity under very poor visibility conditions. At the present time, there are great difficulties associated with these questions.

The requirement for the mentioned flexibility means that various approach profiles must be maintained which could become possible by using new aircraft (STOL, VTOL). In order to cover these flight profiles, it is necessary to enlarge the coverage range of the system within which it provides information which can be evaluated. These represent the most important new requirements. An ideal flight control system should have a hemispherical coverage, but reductions in the coverage occur because of the necessary physical limitations and because of technical difficulties. Figure 5 gives a representation of the maximum coverage requirements. One can distinguish three main coverage regions: approach, landing, and rollout, as well as erroneous approach (takeoff). Except /6 for the range of erroneous approach, information is available along three axis (vertical, lateral, distance). In order for the system to satisfy all these coverage requirements, more or less technical complexity will be involved. Therefore, it is planned to reduce the system into individual components or system configurations, each having a low coverage, down to a minimum system. This is essentially done because of the costs involved. The requirement for control during the leveling off phase requires additional complexity, which in most systems can only be satisfied by an additional subsystem. It is debateable whether or not the requirement for leveling out control are general ones, or whether this is a special case for special applications, which a special system would satisfy anyway. This special system would not have to be an integral component of the standard system. I would like discuss the individual coverage regions in more detail.

Approach range: For the first time, the new approach and landing system covers the region of extended approach, in addition to the region of landing. We intend to introduce curved approach paths in this region, asssuming that angular and distance information will be used. The most important reasons for this were already mentioned. This includes the increase in capacity and the application of noise-reducing approach methods. The extension of this range, especially considering the information from other navigation installations already available for the short-range traffic region, has been roughly estimated to lie between 20 and 30 NM. The lateral coverage is a compromise which was brought about because of the possibilities of certain systems. Of course, in order to satisfy all the conditions, coverage over a circle would be ideal. Coverage of the predicted or somewhat extended range would already represent a navigation aid for the short-range

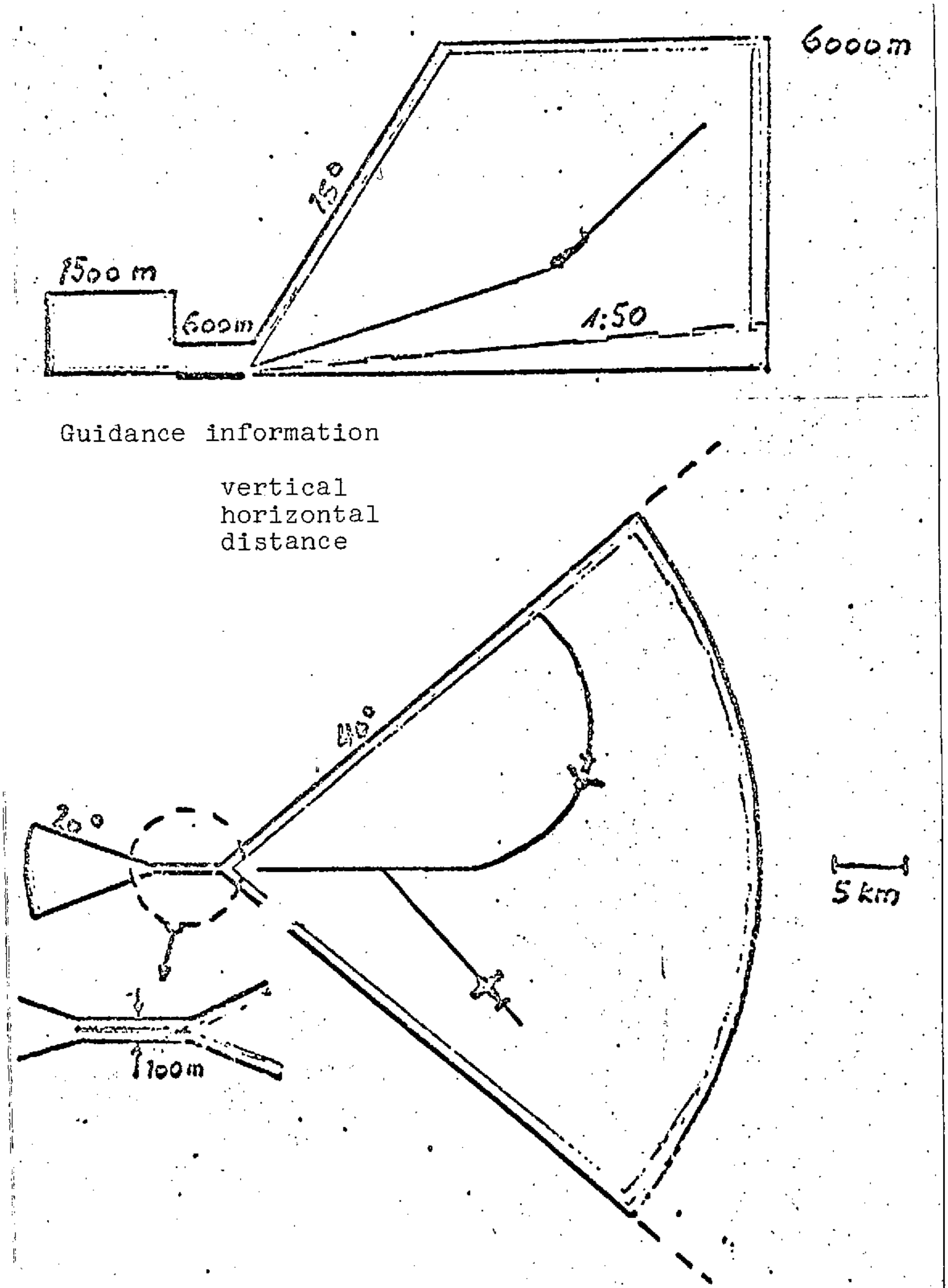


Figure 5. Approach and landing system ICAO.

traffic region, so that other aids could be dropped under certain conditions (quasi-TMA). It still remains to be determined to what extent such coverage will be required for use in the short-range traffic region, which is already well organized. It could be appropriate to use a system with minimum coverage requirements in this range, but it would have to have maximum accuracy. At less important airports, which have their own short-range traffic region or which have deficient coverage of other navigation installations, it is possible for a requirement for a system with maximum coverage to appear, which at the same time will provide navigation coverage for part of the short-range region. The vertical coverage within the approach range is specified in a way (15° or 30°) so that the necessary information will be available for steeper approaches. In simpler versions, it is planned to have selectable straight-line approach profiles which can be selected on board. However, the flight control system can also calculate and follow arbitrarily curved approach paths in both planes because of the available distance and angular information.

Landing: The required lateral coverage in this phase exclusively considers the landing and, therefore, covers only a very narrow range. The accuracy is to ensure that the aircraft will remain along the landing trajectory. By simultaneously specifying the distance, it becomes possible to calculate and consider the remaining roll path, and the accuracy only has /7
to be large enough so that there will be satisfactory connection with a possible roll control system. The information for vertical control extends to the ground and its accuracy is sufficient to provide an independent leveling off control to the aircraft. This is especially required if very poor approach terrain is considered, where it will hardly be possible to use a radio altimeter. As already mentioned, the introduction of

levelling off control requires extensive additional effort and is, therefore, debatable. The use of the information for landing can, of course, also conversely be used for takeoff under very poor visibility conditions.

Erroneous approach: In this case, there is a requirement for lateral information. The information must be provided along the landing trajectory up to a certain altitude. In this way, one hopes to reduce the protection areas against obstacles required for the erroneous approach. In addition, this range can be used for takeoff and curved approach paths, for example, for noise reducing approaches. However, it should be realized that the planned sector has apparently been selected as too small in this region. Its primary purpose is coverage of erroneous approaches up to a certain safe minimum altitude. A vertical control in the erroneous approach sector is not required. In this case, one can most clearly see the influence of available system designs (costs) on the operational requirements. The absence of vertical information is justified in part by the impossibility in some cases of maintaining a vertical flight profile during a critical phase of flight, which is dependent on very many factors (available thrust power, flight weight).

Accuracy: No specific numbers have been mentioned for the required accuracy. It is assumed that these values will develop secondarily from the satisfactory compliance with the operational requirements and that they will be system-specific.

The present operational requirements of the ICAO for a new approach and landing control system were produced from the requirement for a timely international standardization. They consider the previous knowledge and the requirement for increased capacity and the use of new aircraft types. Nevertheless, many points have not yet been completely clarified, especially the interaction with the so-called future systems (data link, TMA, new control methods, flight control). The corresponding panels have also realized that these operational requirements are of a preliminary nature and have requested that the additional investigations be made in order to support the assumptions made or changes to them. Among these, we have in particular the following: 1) erroneous approach control and related problems; 2) takeoff control; 3) coverage with signal information; 4) possibilities of use for curved and broken flight profiles; 5) relationships between the control system, its capacity, and those of the flight safety system.

At the present time, there is the danger that because of pressure from industry or certain interest groups, a system will be developed too early, without considering these additional points, or that they will not be considered adequately. Potential users can withstand this pressure because they fear that intermediate solutions and fragmented systems will be developed. From the operational point of view, we must require that the new system will nevertheless adapt itself to the flight safety system of the future (on board and on the ground) and will /8 satisfy all special requirements which exist for approach and landing.

4. What Does the Future Hold (Realization)?

At the present time, there are a number of national programs in various countries which are developing a system corresponding to the operational requirements. Here there is clearly the danger that various system concepts will be manifested which later on will compete with each other. On the other hand, one can welcome a certain amount of competition in this area. ICAO recognized this danger from previous experience and therefore, made attempts to become involved in this development process at the right time. It is understandable that this organization itself cannot be an institute which furthers the development, because it is supported by the help of the individual member states. The ICAO therefore has requested of the member states to submit to it available system concepts, as required by each country, in the form of a system concept for the ICAO. This means that all those system concepts which are not financially supported by a country will become automatically excluded. The deadline for submitting suggestions just was passed recently and the countries have submitted their proposals or will submit them soon. Within the framework of the ICAO, the AWOP group will first concern itself with a preliminary review and evaluation, which later on will lead to a preliminary classification. This will then be transmitted to the member countries. The other activity of the ICAO will consist of advisory services and support of the states. An attempt will be made to work up evaluation criteria which are as uniform as possible. The final decision for a system will then be carried out on a world-wide scale using the recommendations and evaluations worked up by the AWOP group. The year 1977 is now considered to be the deadline for the final acceptance of a system concept or of a system specification. From this, we may derive the year 1980 as the beginning of the introduction of such a system.

According to data now available, the United States, Great Britain, Australia, West Germany, and ..... are participating in this system competition. It would be very interesting to investigate and discuss the system designs and their realizations submitted by the individual countries, as well as their realization. However, this would go outside of the framework used in my discussion. In general, it can be said that any system which would emerge from a final selection will satisfy the operational requirements in principle, which would then cover the already mentioned operational modes of the future. In addition to the technical concepts and the question of the cost/benefit ratio, it is certain that different philosophies regarding the ground derived/air derived system or regarding the adaptation of the system to the flight safety system of the 1980's will develop. However, at the present time, it would be too early to make statements regarding this topic, and this will be discussed in a future paper.

I hope, in this way, to have given you a summary on the problem of the relationship between flight operations and flight control systems, which will then represent an introduction for the following submitted papers.

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